3 INCIDENCE AND ENVIRONMENTAL EFFECTS OF OIL AND GAS RELEASES

Oil and gas development typically involves three phases: exploration, well completion and site construction, and operation of extraction and processing facilities. Related activities include the transport of extracted oil and gas to large storage and distribution facilities and transportation to refineries. Much of the available information regarding environmental effects is related to effects from the accidental releases of oil or gas from a variety of sources (i.e., pipelines, tanker trucks and ships, and wellheads) and a variety of causes (i.e., pipeline ruptures, truck accidents, tanker ship groundings, and well blowouts). Environmental effects associated with the large-scale storage, transportation, and processing of oil and natural gas (e.g., refineries) are outside the scope of this study and are not addressed in this report. Current levels of oil and gas production in the Great Lakes Basin states are discussed in Section 5.7.

3.1 OIL AND GAS RELEASE INCIDENTS

A number of sources account for oil spills. Tanker accidents have accounted for most of the world's largest individual spills, but are much less frequent than spills from other sources such as pipeline breaks, leaking storage tanks, offloading accidents, refinery accidents, and truck and train accidents (NOAA 2005a). For example, in 2001, spills from fixed platforms and onshore and offshore pipelines accounted for about 8.7% of the total number of spills and 8.9% of the total spill volume reported by the Coast Guard for U.S. waters under Coast Guard jurisdiction (including the Great Lakes) (USCG 2003). In inland waters under EPA jurisdiction (excluding the Great Lakes, there were approximately 43,000 spills, totaling more than 300 million gal (1,135 L), reported between 1980 and 2000 (Etkin 2004). About 80% of the total volume of these spills was due to releases from pipelines and other facilities. Nearly 40% of the spills had no reported causes, while structural failure accounted for the greatest percentage of number (24%) and volume (42%) of the known causes, and operational errors accounted for 22% of the spills.

More than 2,000 land-based oil and gas wells have been directionally drilled in Michigan since the 1970s (MESB 1997). According to insurance industry data, there have been no reported incidents at the more than 3,800 directional well bores drilled in Michigan, including 13 beneath the Great Lakes (LaFaive 2002). Approximately 2,200 wells have been drilled to date on the Canadian side of Lake Erie, and there are currently about 594 commercial wells in the lake. Only gas production, not oil production, is allowed in the lake on the Canadian side potentially because of greater concerns for oil spills than for accidental gas releases. Gas production is prohibited if hydrocarbon liquids are encountered with the gas production (Borawski 2005).

Since 1959, there have been three oil spill incidents on the Canadian side of Lake Erie, of which only one was directly attributed to a drilling operation (Borawski 2005). In that incident, about 210 gal (795 L) of fuel oil were accidentally released from a drill rig into the lake. There have been no reported oil releases from subsurface formations into overlying waters during any Canadian drilling or production operations.

Between 1969 and 2001, the number of oil spills from all sources (such as tanker spills, platform releases, pipeline leaks, refinery accidents, tanker truck accidents) reported from the Great Lakes by the U.S. Coast Guard (USCG 2003) has ranged from as few as 2 spills in 1983 to as many as 282 spills in 1995, with an annual average of 135 spills over that time period (Table 3.1). In comparison, spills reported during this same time period for East and West Coast harbors ranged from a low of 692 spills in 1987 to a high of 4,015 spills in 1974, with an annual average of 1,712 spills. The volumes of the spills reported from the Great Lakes ranged from 11 gal (42 L) in 1983 to 179,912 gal (681,041 L) in 1976, with an annual average volume of 41,121 gal (155,660 L) (Table 3.1). The volumes of the spills in coastal harbors during this same time period ranged from 45,932 gal (173,872 L) in 1997 to more than 7.6 million gal (28.8 million L) in 1984. A total of 239,053 spills were reported by the Coast Guard from 1973 to 2001 in all U.S. waters (e.g., Atlantic and Pacific Oceans, Gulf of Mexico, Great Lakes, lakes, rivers, channels, harbors, and other). Spills in the Great Lakes represent 1.6% of this total (USCG 2003); this low contribution is due to the much greater amount of oil and gas transportation that occurs on the East and West Coasts than in the inland waters of the Great Lakes. Spills from pipelines accounted for approximately 3.4% (8,076 spills) of the total spills reported from 1973 through 2001, while spills from facilities (i.e., oil platforms, refineries, factories, and industrial facilities) accounted for about 27% of the total spills reported during that time.

TABLE 3.1 Oil Spills in the U.S. Great Lakes and Coastal Harbors, 1973–2001

Location	Annual Number of Spills – Range	Annual Number of Spills – Average	Annual Volume of Spills – Range (gal)	Annual Volume of Spills – Average (gal)
Great Lakes	2–282	135	11–179,912	41,121
Harbors[a]	692–4,015	1,712	45,932–7,604,388	1,180,719

[a] Harbors along the East and West Coasts.

Source: USCG (2003).

In an evaluation of the characteristics of inland freshwater and coastal marine oil spills, Yoshioka and Carpenter (2002) reported that for 1995 and 1996, 77% of all spills greater than 1,000 gal (3,785 L) and 88% of spills greater than 10,000 gal (37,854 L) occurred at inland freshwater locations. More than half of all inland spills (56%) were attributed to pipelines, while vessels accounted for the majority of coastal spills. Yoshioka and Carpenter (2002) also found inland spills to be more likely than coastal spills to occur near populated areas or biologically sensitive areas.

The U.S. Department of Transportation Office of Pipeline Safety (OPS) reports a total of 2,580 pipeline incidents occurring in the United States between 1986 and 2004 (OPS 2005). These incident summaries do not identify the type or volume of the release; they do, however, identify the causes of the incidents, which include construction defects, accidental excavation, weld failure, lightning, and earth movement. The total number of incidents reported from 1986 through 2004 was 2,580, ranging from a low of 97 incidents in 1995 to a high of 201 incidents in1988 (OPS 2005). These incidents resulted in 318 fatalities and 1,404 injuries, as well as more than $350 million in property damage.

3.2 ENVIRONMENTAL EFFECTS OF HISTORIC RELEASES

Between 1967 and 1991, there were 53 major spills (>10,000 barrels) in U.S. waters (NOAA 1992). The majority of these spills occurred in coastal areas, although one such large release occurred within the Great Lakes Basin in the Saginaw River in Michigan. That spill occurred on September 16, 1990, when a tanker caught fire and exploded while offloading about 20,000 barrels of unleaded gasoline at a refinery on the Saginaw River near Bay City, Michigan. The wake from a passing bulk carrier is believed to have caused the parting of the tanker's transfer hose, grounding cable, and all but one mooring line. Residual gasoline from the broken transfer hose was believed to have then ignited, and the ship swung into the river and grounded perpendicular to the direction of stream flow, cracking its hull. The fire was finally extinguished on September 18.

As a result of the release, area marinas were evacuated, and vessel traffic in the river halted. A 3-in.-(8-cm)-thick layer of gasoline was observed around the hull of the tanker. With the use of a containment boom and vacuum trucks, approximately 262 gal (992 L) of gasoline/water mixture were recovered, and small amounts of carbon residue were manually removed from beaches in the area. Little environmental damage was reported; a small number of fish were killed by the shock waves of the explosion rather than exposure to the gasoline.

While very limited environmental effects were reported for this spill, most of the other spills discussed in the case studies report produced a range of environmental effects. These include the fouling of beaches (Figure 3.1) and wetlands, mortality of ducks and diving birds such as cormorants and gulls from oiling (Figure 3.2), mortality of fish embryos, increased contaminant concentrations in fish, shellfish, ichthyoplankton (larval fish), and zooplankton (microcrustaceans), although relatively few long-lasting impacts were identified for many of the spills (NOAA 1992).

In contrast to the relatively limited environmental impacts identified for many of the spills described in the NOAA report (NOAA 1992), the Exxon Valdez spill resulted in a variety of environmental affects, some of which have lasted for more than 10 years following the initial spill Rice 2002). The Exxon Valdez ran aground on March 24, 1989, spilling approximately 10.9 million gal (41.2 million L) of Prudhoe Bay crude oil; this is the largest oil spill to date in U.S. waters. The spill soiled shorelines for up to 500 mi (805 km) of Alaskan coastline. The grounding

FIGURE 3.1 Example of a Very Large Oil Spill Washing Ashore (Source: EPA 2005f)

occurred at the beginning of the bird migration season, and the U.S. Fish and Wildlife Service (USFWS) estimated that between 350,000 and 390,000 bird mortalities could be directly attributed to the spill; birds especially affected included common and thick-billed murres (small diving birds related to puffins). An estimated 3,500 to 5,500 sea otter and 200 harbor seal mortalities were also attributed directly to the spill. These wildlife mortalities were directly related to extensive oiling rather than to acute toxicity. Concerns regarding contamination of fish and shellfish resulted in the cancellation of the 1989 black cod season in Prince William Sound, banned fishing for Pacific herring, and a reduced shrimp season.

FIGURE 3.2 Example of an Avian Mortality from Extreme Oiling (Source: EPA 2005f)

Although a massive cleanup effort was initiated that lasted several years, long-term effects have resulted from residual oil that remained in the environment. Population impacts to pink salmon from reduced egg survival and increased larval deformities, lasted for more than 4 years in some areas, while populations of sea otter and sea ducks had not recovered to prespill levels 10 years following the spill. Elevated concentrations of oil components have been detected in a variety of vertebrate and invertebrate biota (Rice 2002).

3.3 FATE OF SPILLED OIL

Once released into the environment, oil may undergo a variety of natural processes that may act to reduce the severity of a spill, or accelerate the decomposition of the spilled oil into forms that are less environmentally hazardous. Five natural processes have been identified as particularly important to the fate of oil in the environment: (1) weathering, (2) evaporation, (3) oxidation, (4) biodegradation, and (5) emulsification.

3.3.1 Weathering

Weathering represents a series of physical and chemical changes that cause the spilled oil to break down and become heavier than water. Wind, waves, and currents may result in the natural dispersion of an oil slick, breaking it into droplets that become suspended within the water column (EPA 2004a).

3.3.2 Evaporation

Oil is a complex mixture of hundreds of organic substances dominated by hydrocarbons. Evaporation occurs when the lighter substances within the oil mixture become vapors and enter the atmosphere. This process leaves behind the heavier components of the oil, which may undergo further weathering and, when in a water body, sink (EPA 2004a). Spills of lighter refined products, such as kerosene and gasoline, contain a high proportion of flammable components and may evaporate within a few hours. Heavier oils are also likely to evaporate. The heavier oils that remain may leave a thicker, more viscous residue that is difficult to remove from beaches.

3.3.3 Oxidation

In water, oil may combine with oxygen to produce water-soluble compounds. This process affects oil slicks mostly around their edges (EPA 2004a). Thick oil slicks may only partially oxidize, resulting in the formation of tar balls — dense, sticky black spheres that may remain in the environment for a long time — which can collect in sediments, or wash up on beaches long after a spill.

3.3.4 Biodegradation

Biodegradation refers to the breakdown of oil by microorganisms such as bacteria. For biodegradation to proceed, nutrients such as nitrogen and phosphorus must be present. These are sometimes added to the water during cleanup response actions at oil spill sites. Biodegradation seems to work best in warmer waters (EPA 2004a).

3.3.5 Emulsification

Emulsification is a process that forms emulsions, that is, mixtures of small droplets of oil and water. These are formed by wave action and act to hamper weathering and cleanup processes (EPA 2004a). Oil and water emulsions cause oil to sink, and thus the oil may linger in the environment for months or years.

3.4 EFFECTS OF OIL RELEASES

Crude oil (oil that has not been refined) is classified into four categories (Table 3.2) that differ in how the oil may react (e.g., how quickly it weathers, whether it forms tar balls) when released to the environment and also its toxicity and potential for adversely impacting the environment.

In addition to the oil itself, some hazardous, toxic, and carcinogenic materials may be present at many oil production sites. These materials (such as hydrogen sulfide [H_2S], benzene, radium, heavy metals, toluene, and xylenes) are associated with the construction, operation, or maintenance of pipelines, storage tanks, and processing facilities, as well as by-products of the drilling process (see Section 2.3.1). For example, some of these chemicals may be added to drilling muds, which are used to lubricate the drill bit as it grinds through the rock layer. As a result of this addition the drilling muds may contain heavy metals and other toxic substances.

TABLE 3.2 Types of Crude Oil

Oil Type	Characteristics
Class A: Light, Volatile Oils	Highly fluid, often clear, spread rapidly on solid and water surfaces, have a strong odor and high evaporation rate, are usually flammable, penetrate porous surfaces (such as sand and dirt), and may be persistent in such matrixes. Class A oils do not tend to adhere to surfaces and are flushed readily with water. Class A oils are highly toxic to humans and biota. Because they are highly fluid, they have the potential to move through the soil and impact groundwater.
Class B: Nonsticky Oils	Have a waxy or oily feel, are less toxic but adhere more than Class A oils. They can be removed from surfaces with rigorous scrubbing. At warmer temperatures, they become less viscous and may more easily penetrate porous surfaces. Evaporation of volatiles may lead to a Class C or D residue. May be persistent in the environment.
Class C: Heavy, Sticky Oils	Characteristically viscous, sticky, or tarry, and black or brown. Flushing with water has little effect on their removal from surfaces, but because of their thickness, these oils do not readily penetrate porous surfaces. The density of Class C oils is near that of water, and thus they often sink when released into a water body. Weathering or evaporation may produce solid or tar-like Class D residues. Toxicity is low, but wildlife may be smothered or drowned when contaminated (see Figure 3.2).
Class D: Nonfluid Oils	These oils are relatively nontoxic, do not penetrate porous surfaces, and are usually black or brown in color. When heated, these oils may melt and coat surfaces making cleanup very difficult.

Source: EPA (2004b).

Depending on its form (Table 3.2) and chemistry, oil can cause an array of physiological and toxic effects. For example, benzene is a known carcinogen and is toxic to humans and wildlife. Some petroleum hydrocarbons are toxic to organisms but less persistent in the environment, while others tend to be less toxic, but more persistent and more likely to result in long-term environment effects. As previously discussed, a number of factors govern the behavior and fate of an oil spill, including the particular chemistry of the crude oil and refined petroleum products and wind and water conditions, any of which may interact to determine the nature and magnitude of any environmental effects.

Freshwater areas are important to human health and the environment and are sensitive to oil spills. They are often used for drinking water and frequently serve as nesting grounds and food sources for various freshwater organisms. All types of freshwater organisms are susceptible to the effects of spilled oil, including fish, insects, microorganisms, vegetation, birds, and mammals. Because many of the organisms that would be affected by an oil spill in a freshwater environment are important components of food chains, impacts to these biota may very likely affect species not directly exposed to the release but that are higher on the food chain and rely on the exposed biota for their food (EPA 2004c).

The nature and magnitude of the effects of an oil spill on freshwater habitats depend on the rate of water flow and the habitat's specific characteristics. Standing water such as wetlands with little water movement are likely to incur more severe impacts than flowing water because spilled oil will tend to collect in the habitat and can remain there for long periods of time. With calm water conditions, the affected habitat may take years to recover (EPA 2004c).

Lake and stream bottoms may support a diverse flora and fauna, including worms, insects, and shellfish. Lake and stream bottoms also serve as breeding grounds and feeding areas for these organisms and higher organisms. Oil in sediments may be very harmful because sediment traps the oil and affects the organisms that live in or feed off the sediments.

In aquatic habitats, oil can be toxic to the frogs, reptiles, fish, waterfowl, and other animals that live in or otherwise use the water (EPA 2004c). Oiling may affect not only wildlife but also plants that are rooted or float in the water, harming both the plants and the animals that depend on them for food and shelter. Freshwater fisheries are also subject to the toxic effects of oil. Aquatic insects that skim the surface and floating plants such as water lilies are threatened by oil slicks that spread across the water surface.

Terrestrial, emergent, and submerged vegetation in shoreline habitats provides many important functions for fish and wildlife. It serves as a food source and provides nesting grounds and shelter for fish and wildlife. Oil spills can coat these areas, thereby affecting the plants and the organisms that depend on them (EPA 2004c). Wetlands are among the most sensitive freshwater habitats to oil spills because of their minimal water flow. Impacts to these habitats may adversely affect a wide variety of biota that use the wetlands as nurseries, feeding areas, and shelter.

Oil spills impact flowing water less severely than standing water because the currents provide a natural cleaning mechanism. Although the effects of oil spills on river habitats may be less severe or last for a shorter amount of time than those on standing waters, the sensitivity of river and stream habitats is similar to that of standing water, and riverine systems may distribute exposure over a wider area (EPA 2004c).

An oil spill may affect biota by (1) direct physical contact, (2) toxicity, and (3) impacts to food sources (EPA 2004d). With physical contact, the body of the exposed organism comes in contact with and is covered by the spilled oil. In birds and mammals, this oiling mats the feathers or fur, causing these to loose their insulating properties, and placing animals at risk of freezing to death. With aquatic mammals and especially birds, this loss of insulation also reduces the buoyancy of the exposed organism, thus increasing the risk of drowning.

Many species will experience toxic effects when exposed to oil (EPA 2004d). Oil exposure has been shown to affect the central nervous system, organ function, reproduction, and development. Species not directly exposed to the oil spill may nonetheless be affected if the spill has affected their prey. In some cases, the abundance of prey may be reduced or even completely lost. In other cases, higher organisms may be secondarily exposed to the oil spill by eating prey that have been contaminated and subsequently incur toxicological effects.

3.5 EFFECTS OF NATURAL GAS RELEASES

As with oil, the composition of natural gas varies, depending on its origin, type, genesis, the location of the deposit, the geological structure of the region, and other factors. Natural gas chiefly consists of a mixture of hydrocarbons (i.e., methane and its related compounds) and carbon dioxide. In addition, H_2S may account for as much as 30% of natural gas by weight. Natural gas containing H_2S is termed sour gas, and before it can be safely used the H_2S must be removed at a processing plant. Hydrogen sulfide is a colorless gas with a characteristic odor of rotten eggs. It naturally occurs in the gases from volcanoes, sulfur springs, undersea vents, swamps, and stagnant bodies of water, and in some crude petroleum and natural gas accumulations. In addition, bacteria, fungi, and other microorganisms may release H_2S during the decomposition of organic materials. Hydrogen sulfide is frequently encountered in various industries and may be released to the environment as a result of their operations. Some of these industries include natural gas production, municipal sewage pumping and treatment plants, landfilling, swine containment and manure handling, pulp and paper production, construction in wetlands, asphalt roofing, pelt processing, petroleum refining, petrochemical synthesis, coke production plants, viscose rayon manufacture, sulfur production, iron smelting, and food processing (ATSDR 2004).

Natural gas exhibits negligible solubility in water, and thus has little affect on water quality in the event of an underwater leak. For terrestrial releases, exposure to an accidental natural gas leak may result in asphyxiation as a result of oxygen displacement, and the greatest threat from a natural gas leak is explosion and fire. In contrast, the greatest concern from an accidental release of H_2S is asphyxiation (also as a result of oxygen displacement) and, to a lesser degree, toxic effects from inhalation. Currently, the Occupational Safety and Health Administration (OSHA) has established an acceptable ceiling concentration of 20 parts per million (ppm) for H_2S in the workplace, with a maximum level of 50 ppm allowed for 10 minutes maximum duration if no other measurable exposure occurs. The National Institute for Occupational Safety and Health (NIOSH) has set a maximum Recommended Exposure Limit ceiling value of 10 ppm for 10 minutes maximum duration (ATSDR 2004). Concentrations in ambient air from natural sources have been reported to range between 0.11 and 0.33 parts per billion (ppb), with no visible adverse effects on indigenous biota at concentrations of 3.9 ppm, while concentrations at landfills and sewage treatment plants have been reported to reach peaks of 100 ppm (ATSDR 2004).

Exposure to low concentrations of H_2S may cause irritation of the eyes, nose, or throat, as well as difficulty in breathing in asthmatic individuals (ATSDR 2004). Brief exposures to high concentrations (greater than 500 ppm) can cause respiratory irritation, fluid buildup in the lungs, convulsions, loss of consciousness, and possibly death. Similar effects (to similar exposure levels) have been observed in laboratory animals (ATSDR 2004), and may be expected for wildlife exposed at similar levels.

While many individuals have been reported to recover from high exposures with no apparent lasting effects, others may experience long-term effects such as headaches, poor attention span, reduced memory, and poor motor function (ATSDR 2004). Wildlife may be expected to exhibit similar variability in recovery from H_2S exposure.

3.6 OIL SPILL RESPONSE

Oil spills may occur in a variety of settings, and the specific steps taken to respond to the spill will depend on the type and amount of oil discharged, the location of the release, the proximity of the spill to a sensitive environment or resource (e.g., unique habitat, drinking water supply), and other environmental factors (such as weather conditions).

There are two major steps in the control and cleanup of an oil spill: containment and recovery (EPA 1999, 2004e). These two steps may be conducted using mechanical equipment, chemical or biological agents, or a combination of mechanical, chemical, and biological methods. In addition, in-situ (in-place) burning of the spilled oil may also be used to clean up an oil spill.

3.6.1 Mechanical Containment and Recovery

With mechanical containment, specialized equipment may be used to minimize the spread of the spilled oil, prevent its transport to sensitive areas, and to concentrate the spilled material into a thicker layer which makes its removal easier.

Booms are the primary tool used for containing oil spills in aquatic systems. While booms may vary in their design and construction, they all generally share the following four basic elements:

- An above-water “freeboard” to contain the oil and prevent waves from splashing oil over the top of the boom;
- A flotation device;
- A below-water “skirt” that contains the oil and helps prevent oil from moving under the boom; and
- A “longitudinal support,” usually a chain or cable running along the bottom of the skirt, that strengthens the boom against wind and wave action, and that may serve as a weight or ballast to add stability and help keep the boom upright.

All booms are affected by water conditions, and their effectiveness decreases with increasing wave or swell heights.

Booms can be fixed to a structure, such as a pier or a buoy, or towed behind or alongside one or more vessels. When stationary or moored, the boom is anchored below the water surface. It is necessary for stationary booms to be monitored or tended because of changes produced by shifting tides, currents, winds, or other factors that influence water depth, direction, and force of motion. Boom tending requires round-the-clock personnel to monitor and adjust the equipment. The forces exerted by currents, waves, and wind may significantly impair the ability of a boom to hold oil. Currents may wash oil beneath a boom's skirt. Wind and waves can force oil over the top of the boom's freeboard or even flatten the boom into the water, causing it to release the contained oil. Mechanical problems and improper mooring can also cause a boom to fail.

When a spill occurs and no containment equipment is available, barriers can be improvised from such materials as wood, plastic pipe, inflated fire hoses, automobile tires, and empty oil drums. They can be as simple as a board placed across the surface of a slow-moving stream, or a berm built by bulldozers pushing a wall of sand out from the beach to divert oil from a sensitive section of shoreline. Although they are most often used as temporary measures to hold or divert oil until more sophisticated equipment arrives, improvised booms can be an effective way to deal with oil spills, particularly in calm water such as streams, slow-moving rivers, or sheltered bays and inlets.

Once a spill has been contained, oil removal is typically initiated using one of three different types of equipment: booms, skimmers, and sorbents. Booms and skimmers are suitable for spills on surface waters, while sorbents may be used for spills on water and on land.

A recovery boom is suspended from a horizontal arm that extends off one or both sides of a vessel. The recovery vessel sails through the heaviest sections of the spill at low speeds, scooping and trapping the oil between the angle of the boom and the vessel's hull. Alternately, a recovery boom may be moored at the end points of a rigid arm extended from the recovery vessel, forming a "U"- or "J"-shaped pocket that collects the oil. In either case, the trapped oil is then pumped to a holding tank and returned to shore for proper disposal or recycling.

A skimmer is a device that recovers oil from the water's surface. Skimmers may be self-propelled and may be used from shore or operated from vessels. The efficiency of skimmers depends on weather conditions. There are different types of skimmers, each offering advantages and drawbacks, depending on the type of oil being cleaned up, the conditions of the sea during cleanup efforts, and the presence of ice or debris in the water.

Weir skimmers use a dam or enclosure positioned at the oil/water interface to contain the trapped oil and water mixture, which can then be pumped out through a pipe or hose to a storage tank for recycling or disposal. Oleophilic (oil-attracting) skimmers use belts, disks, or continuous mop chains of oleophilic materials to blot the oil from the water surface, which is then squeezed out or scraped off into a recovery tank. Oleophilic skimmers have the advantage of flexibility, allowing them to be used effectively on spills of any thickness. Suction skimmers operate like a vacuum cleaner, sucking the oil up through wide floating heads and pumping it into storage tanks. Suction skimmers operate best on smooth water where oil has collected against a boom or barrier.

Sorbents recover oil by absorbing and/or adsorbing the spill. Absorbents allow oil to penetrate into pore spaces in the material they are made of, while adsorbents attract oil to their surfaces but do not allow it to penetrate into the material. Although they may be used as the sole cleanup method in small spills, sorbents are most often used to remove final traces of oil, or in areas that cannot be reached by skimmers. Sorbents may be made of natural organic, natural inorganic, or synthetic materials.

Natural organic sorbents include peat moss, straw, hay, sawdust, ground corncobs, feathers, and other carbon-based products. Organic sorbents can soak up from 3 to 15 times their weight in oil, but they do present some disadvantages. Some organic sorbents tend to soak up water as well as oil, causing them to sink. Many organic sorbents are loose particles, such as sawdust, and are difficult to collect after they have been applied onto the water. Natural inorganic sorbents include clay, perlite, vermiculite, glass, wool, sand, and volcanic ash. They can absorb from 4 to 20 times their weight in oil. Synthetic sorbents are man-made materials similar to plastics, such as polyurethane, polyethylene, and nylon fibers, and can absorb as much as 70 times their weight in oil.

For spills in shoreline and terrestrial environments, spill cleanup may include wiping with sorbents, pressure washing, raking, and bulldozing. Sorbents in the form of towels and mops may be used to wipe oily rocks and soils. Pressure washing involves rinsing oiled shorelines and rocks with low- or high-pressure, hot or cold water to flush the oil into plastic-lined trenches for collection with sorbents. Low-pressure water may be used to clean oiled vegetation. Raking and bulldozing involves the disturbance or removal of sand, gravel, pebbles, cobble, or soil into which oil has moved. If the oil is limited to the shallow subsurface, tilling or raking the substrate exposes the oil to air and sunlight, potentially speeding evaporation and natural degradation. For oil in deeper soils, bulldozers are used to bring the contaminated soils to the surface for removal, pressure washing, or biodegradation.

3.6.2 Chemical and Biological Containment and Recovery

Chemical and biological treatment of oil can be used in place of mechanical methods to contain and recover spills, especially in areas where untreated oil may reach shorelines and sensitive habitats where a cleanup becomes difficult and environmentally damaging (EPA 1999, 2004e). Such treatment typically uses dispersing agents and/or biological agents.

Dispersing agents, also called dispersants, are chemicals that contain compounds (surfactants) that act to break the oil into small droplets. The small oil droplets then disperse into the water column where they are subjected to natural processes such as wind, waves, and currents that help to break them down further. Dispersing agents thus hasten the removal of oil from the water surface, making it less likely that the oil slick will reach a shoreline. The effectiveness of a dispersant is determined by the type of the oil that is being treated and the method and rate at which the dispersant is applied. Heavy crude oils do not disperse as well as light- to medium-weight oils. Dispersants are most effective when applied immediately following a spill, before the lightest components in the oil have evaporated.

Environmental factors such as water salinity and temperature, as well as surface water conditions impact effectiveness; many dispersants work best at salinity levels close to that of normal seawater and in warm water (EPA 1999). Some countries rely almost exclusively on dispersants to combat oil spills because frequently rough or choppy conditions at sea make mechanical containment and cleanup difficult. However, dispersants have not been used extensively in the United States because of difficulties with application, disagreement among scientists about their effectiveness, and concerns about the toxicity of the dispersed mixtures. Dispersants used today are much less toxic than those used in the past, but few long-term environmental effects tests have been conducted after a dispersant application.

Biological agents are nutrients, enzymes, or microorganisms that increase the rate at which natural biodegradation occurs. Biodegradation of oil is a natural process that may take weeks, months, or years to remove oil from the environment. However, rapid removal of spilled oil from shorelines and wetlands may be necessary in order to minimize potential environmental damage to these sensitive habitats. By speeding up the rate of biodegradation, biological agents speed up the breakdown of the spilled oil and its conversion to less harmful compounds.

The addition of biological agents such as fertilizers or microorganisms to increase the rate at which natural biodegradation occurs is termed bioremediation. This approach is often used after all mechanical oil recovery methods have been used. Two bioremediation approaches have been used in the United States for oil spill cleanups: biostimulation and bioaugmentation. Biostimulation involves the addition of nutrients such as phosphorus and nitrogen to a contaminated environment (beaches, shorelines, and inland soils) to stimulate the growth of the naturally occurring microorganisms that break down oil. Bioaugmentation is the addition of microorganisms to the existing native oil-degrading biota to increase the population of microorganisms that can biodegrade the spilled oil. Bioaugmentation is seldom used, however, because hydrocarbon-degrading bacteria exist almost everywhere and nonindigenous species are often unable to compete successfully with native microorganisms.

3.6.3 In-Situ Burning

In-situ burning involves the ignition and controlled combustion of the spilled oil. It can be used when oil is spilled on a water body or on land. The National Oil and Hazardous Substances Contingency Plan authorizes in-situ burning as a cleanup method but requires EPA approval before it can be used. In-situ burning is typically used in conjunction with mechanical recovery on open water. Fire-resistant booms are used to collect and concentrate the oil into a slick that is thick enough to burn. Factors influencing the decision to use in-situ burning on inland or coastal waters include water temperature, wind direction and speed, wave amplitude, slick thickness, oil type, and the amount of oil weathering and emulsification that has occurred (EPA 1999). Oil layer thickness, weathering, and emulsification are usually dependent upon the time period between the actual spill and the start of burn operations.

The major issues for in-situ burning of inland spills are proximity to human populations, soil type, water level, erosion potential, vegetation species and condition, and wildlife species presence. Burning may actually allow oil to penetrate farther into some soils and shoreline sediments, and it releases pollutants into the air. Although it can be effective in some situations, in-situ burning is rarely used on marine spills because of concerns over atmospheric emissions and uncertainty about its impacts on human and environmental health. However, burning of inland spills is frequently used in a number of states (EPA 1999).

Despite its drawbacks, in-situ burning may be an efficient cleanup method under certain conditions. These conditions include remote areas away from human use, areas with herbaceous or dormant vegetation, and water or land covered with snow or ice. Under these circumstances, burning can quickly prevent the movement of oil to other areas, eliminate the generation of oily wastes, provide a cleanup means for affected areas with limited access for mechanical or physical removal methods, or provide an additional level of cleanup when other methods become ineffective. When oil is spilled into water containing a layer or chunks of ice, burning can often remove much more oil than conventional means. Burning can also help to eliminate some volatile compounds that might otherwise evaporate off a slick.

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